The Scattering of Hydrogen Positive Rays, and the Existence of a Powerful Field of Force in the Hydrogen Molecule.

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1. *General Scheme of Research.*

In view of the extremely important results obtained by Sir E. Rutherford and others from a study of the scattering of α-rays, it seemed worth while to investigate the scattering of particles moving with smaller velocities such as occur in the positive rays. The most interesting, because the simplest, are the rays of positively charged hydrogen atoms, which presumably consist simply of a nuclear particle, or proton. The experiments described in this paper were made in some cases with these rays, in others with the positively charged hydrogen molecules, systems consisting of two protons and one electron. The scattering medium was in all cases hydrogen gas. This was chosen largely for convenience, as the experimental arrangement is considerably simplified if the same gas is used to produce the rays and to scatter them, and also because, with the exception of helium, the molecule of hydrogen is the simplest known, and there seemed more hope of obtaining results which could be given a definite theoretical interpretation.

The general scheme of experiment was to produce the rays in a discharge tube, analyse them by magnetic and electric fields in the ordinary way, cut off all except those of the kind required by a slotted diaphragm, pass the remainder through a chamber containing the scattering gas, and receive them in a Faraday cylinder arranged behind a slit of variable width. The experiment consisted in finding how the charge received by the Faraday cylinder varied with the width of the slit, when this was made wider than the geometrical "shadow" of the slot in the diaphragm. Any rays lying outside this "shadow" must have been scattered.

The energy of the rays was of the order of 10,000 volts; the pressure of gas in the scattering chamber varied from 1·5 to 12 thousandths of a millimetre of mercury. The scattering observed was of the order of 1°.

The outstanding result of the experiments is that the scattering is many times (10—20) greater than would be expected, on the assumption that the only forces acting are the ordinary forces of electrostatics varying as the inverse square.

2. *Experimental Arrangement.*

The apparatus used is shown in general arrangement in fig. 1, and the slit mechanism in more detail in fig. 2.

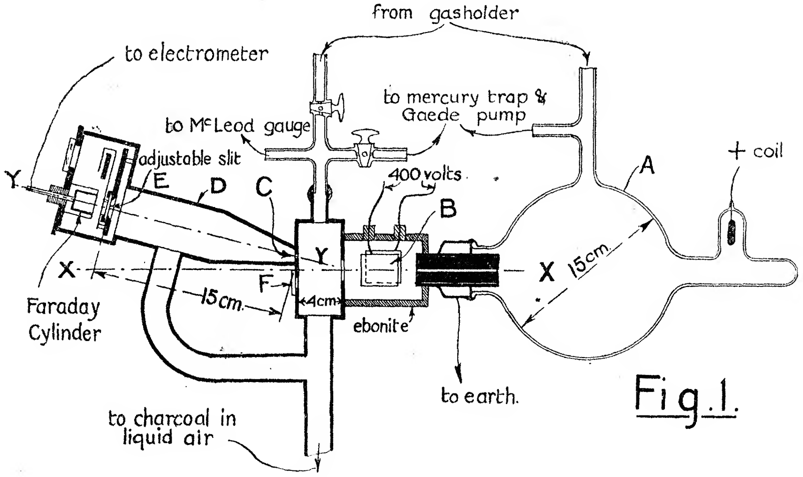


Fig. 1.

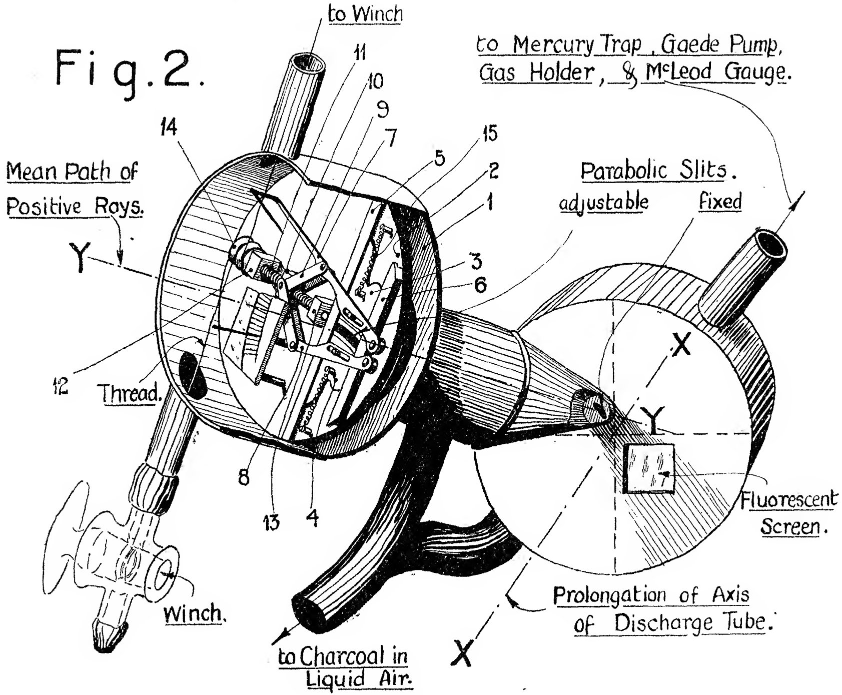

to Winch
to Mercury Trap, Gaede Pump, Gas Holder, & McLeod Gauge.
11
10
9
7
14
15
5
2
1
Mean Path of Positive Rays.
Parabolic Slits.
adjustable
Fixed
Y
3
6
X
12
Thread.
Y
8
13
4
Fluorescent Screen.
Winch.
Prolongation of Axis of Discharge Tube.
to Charcoal in Liquid Air.
X

Fig. 2.

In fig. 1 A is a discharge bulb connected to a Gaede pump as shown, and fitted with a concave cathode pierced by a fine tube of 0·37 mm. diameter and 5·1 cm. length.

The rays passing through this fine tube are analysed by electric and magnetic fields between the plates, B. They then fall on the plate, C, pierced with a parabolic slit 1·2 mm. in width. By adjusting the magnetic field any required type of rays (in practice hydrogen atom or molecule) can be made to pass through the slit and into the scattering chamber, D. The pressure here is kept low by the use of charcoal cooled by liquid air, which also has the effect of removing impurities from the hydrogen, or slight traces of vapour given off from the apparatus. The rays then fall on the adjustable slit, E, which is arranged parallel to the parabolic slit in C. After passing E they are collected in the Faraday cylinder. The width of the slit, E, can be adjusted without disturbing the vacuum by means of two winches, fig. 2, of the type invented by Dr. Aston for lowering a plate in the ordinary photographic type of positive ray apparatus.

The slit mechanism, shown in detail in fig. 2, was designed and made by Mr. W. S. Farren, M.A., and has worked with complete success. In the figure 1 is the airtight face of the chamber, 2 is a base plate, 3 and 4 are the plates which form the slit and move in guides, 5 and 6. They are actuated by slotted levers, 7, 8, moved by links, 9, which are connected to the nut, 10. This is driven by the screw, 11, which is turned by two threads round the pulley, 14, and kept from axial motion by the stops, 12 and 13. All backlash is taken up by the springs, 15, which are always in tension. The width of the slit is determined by reading through a plate-glass window the position of two pointers on the scale as shown, the scale being fastened to a mirror to obviate parallax.

The procedure in an experiment was as follows:—The apparatus was pumped out and a charge of hydrogen admitted from the gas holder. It was then pumped down again till the pressure was a few hundredths of a millimetre, and the taps turned which cut the scattering chamber off from the discharge. The pressure in the scattering chamber was then reduced by means of the charcoal, while the discharge tube was pumped down until a balance was obtained between the pump and a leak through a fine capillary to the gas holder, which was adjusted to give a pressure of the order of 1/100 mm. in the discharge tube.

When the discharge had been running for some little time and the pressure seemed steady, the spots were examined on the willemite screen, F, on to which they were thrown by reversing the field. If these were satisfactory in appearance, the rays were thrown on to the slot in C and so into the Faraday cylinder. This was connected with a Dolazelek electrometer (period 50 seconds), and the current obtained from the rays balanced against a high resistance of xylol and alcohol (resistance of order 10^{12} ohms). The deflection of the electrometer was read on a scale in the ordinary way. A deflection of about 700 mm. corresponded to 1 volt. The slit, E, fig. 1, was first adjusted to a width of about 1·5 mm., and the magnetic field adjusted till the electrometer deflection was a maximum. This ensured that the pencil of rays was correctly centred on the slot, C. The width of E was then gradually increased and the readings of the electrometer taken for various widths of E. At the same time the pressure of the scattering gas was read on a McLeod gauge. The slit was gradually opened and closed several times in the course of an experiment, which might last about three-quarters of an hour. Any irregularity in the running of the coil would, of course, lead to inconsistent results being obtained, and probably slight irregularities of this kind constitute the most important of the experimental errors. It was found, however, that so long as the Cox brake gave a uniform sound, the results so obtained repeated with considerable accuracy over the course of an experiment (see fig. 3). It was found advisable to place a fairly strong electromagnet near the Faraday cylinder. This considerably reduced the deflection, part of which is, no doubt, due to δ-rays caused by the impact of the positive rays. The magnet prevents these from escaping from the cylinder. It was always used during the experiments recorded, and was so strong that further increase of strength had no effect.

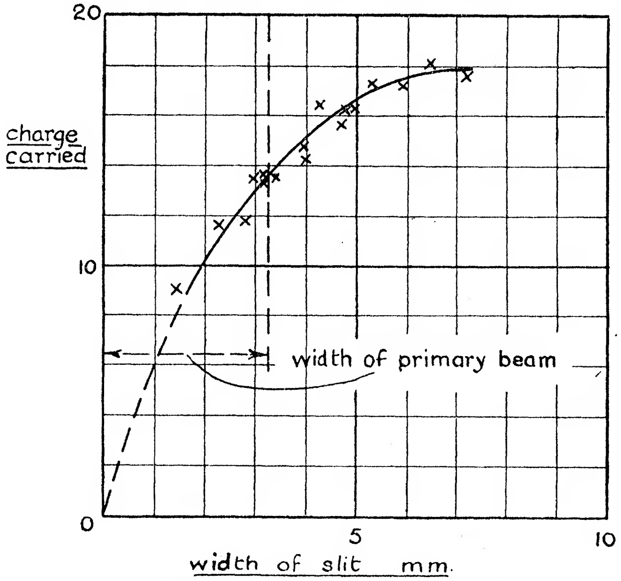
3. *Precautions.*

When it became clear that the scattering observed was greater than would be expected theoretically, a variety of precautions were taken to eliminate possible spurious scattering effects. In the earlier experiments, the action of the charcoal was relied on to purify the gas in the scattering chamber from mercury, of which the spectroscope showed a good deal in the discharge tube. In case this was not really adequate, a mercury trap dipped in liquid air was fitted between the pump and the discharge tube. In this way the mercury was removed until no trace of its spectrum could be seen in the discharge. It was found, however, that there was no perceptible difference in the scattering curves obtained before and after the use of the mercury trap, which was, however, continued as an extra precaution. It was suggested that, in spite of the charcoal, the vapour pressure of the tap grease used might be sufficient to produce an appreciable effect. This possibility is, however, excluded by the fact that perfectly sharp photographs are regularly obtained from apparatus in which winches, lubricated with the same tap grease, are used. Great care was taken to clean the slot at C, but it seemed possible that some minute quantity of dirt might become charged, and by its repulsion of the rays produce an appearance of scattering. To test this, at the end of the research the slot was greatly enlarged so that there was no obstruction anywhere near the rays, but no great difference was found as a result, the only change being a slight *increase* in the scattering over big angles, due, no doubt, to the fact that rays of other kinds were no longer excluded from the scattering vessels.

4. *Readings.*

At the pressures at which the discharge runs best the molecular rays are considerably more numerous than the atomic, and so the results obtained from them are probably more accurate than those obtained from the atomic ones. However, quite sufficient results were obtained with the atomic rays to show that the scattering was nearly the same in the two cases, indeed, it is probably identical within the limits of accuracy of the present apparatus.

A typical curve, with the experimental points marked, is shown in fig. 3.



Molecule. Mean energy 11000 volts
Pressure 4·5 $\frac{\text{mm}}{1000}$.
Fig. 3. Mercury trap used.

In every case the slit was opened and closed several times during the experiment, so that any effect due to a gradual change in the discharge conditions is excluded. The curves show deflection of the electrometer plotted against *total* width of the slit; in order to find the relative number of particles falling on different portions of the slit, it is therefore necessary to find the slope of the curve at the various points. The dotted ordinate shows the width of the slit which could be reached by unscattered particles, and the rise of the curve to the right of this ordinate represents scattering. Owing, however, to the circular section of the fine tube, the distribution of the rays would be by no means uniform apart from scattering. In the area bounded by the dotted ordinate, probably the great bulk of the unscattered rays would fall within considerably narrower limits.

Reduction of Results.—The ideal in an experiment of this kind is to deduce from the quantities measured the probability at each encounter of any specified angle of scattering. Though the data obtained are theoretically sufficient for this to be done, the results with the present experimental arrangement would be so uncertain that no useful purpose is served by performing the reductions. It is hoped, however, by certain modifications of the apparatus, to reach a degree of accuracy which will make this possible in future experiments. The present work must be taken as determining the general magnitude of the effect to an accuracy of 10–20 per cent., and the interest lies in the very large discrepancy between the value obtained and that which would be expected on the ordinary theory (*vide infra*).

In order to compare the results of experiments made at different pressures, it is desirable to find a single quantity which can be regarded as measuring the scattering. If the curves are of different shapes, as one would theoretically expect them to be, it is difficult to find any one quantity which can fairly be compared. Perhaps the best is to take the fraction scattered through a distance greater than some arbitrarily chosen value, but care must be taken in selecting this value. Taking a value which roughly corresponds to the width of the main portion of the unscattered beam, the results obtained are shown in fig. 4. The points lie on a curve which is fairly parabolic for large pressures, but more nearly linear for small pressures. This might be expected. If the number of collisions which is effective in producing measurable scattering rarely exceeds one, the scattering will be directly proportional to the pressure. If the number of such collisions is large, the scattering on the usual probability theory will be proportional to

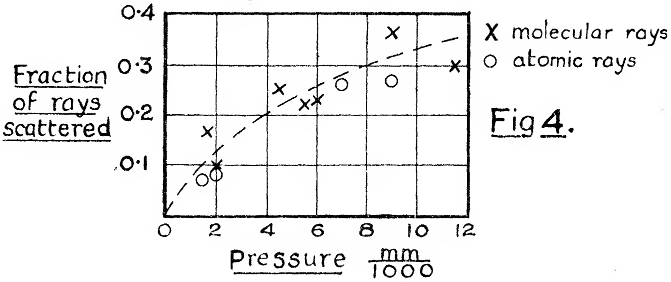


Fig 4.

the square root of the number, and so to the square root of the pressure, giving a parabola. It must not, of course, be assumed that every collision, as calculated from kinetic theory data, will give appreciable scattering, but this number will give an upper limit. However, if this explanation of the shape of the curve is correct, it is perhaps worth noticing that the curvature begins to be marked somewhere near the point where the average particle will have made more than one kinetic theory collision (allowance being made for the speed and size of the rays).

In order to get a more definite measure of the scattering, it was decided to compare the mean curve from four experiments, at not very different pressures, with the curve obtained at the lowest pressure available, modified slightly by exterpolation, to represent as nearly as possible the unscattered beam.

The two curves are shown drawn out in fig. 5, the scales being adjusted to make the total within a slit width of 0·75 mm. come the same. The next stage in reduction would be to take the slopes at various points. It would then be necessary to find from the actual scattering curve the ideal curve due to an infinitely narrow beam. Though this is theoretically possible, it was found to involve such a loss of accuracy as to give a result that was of little value, so the work was not proceeded with, especially as it would then have been necessary to allow for the fact that the scattering occurred throughout the volume of the chamber instead of being concentrated in a

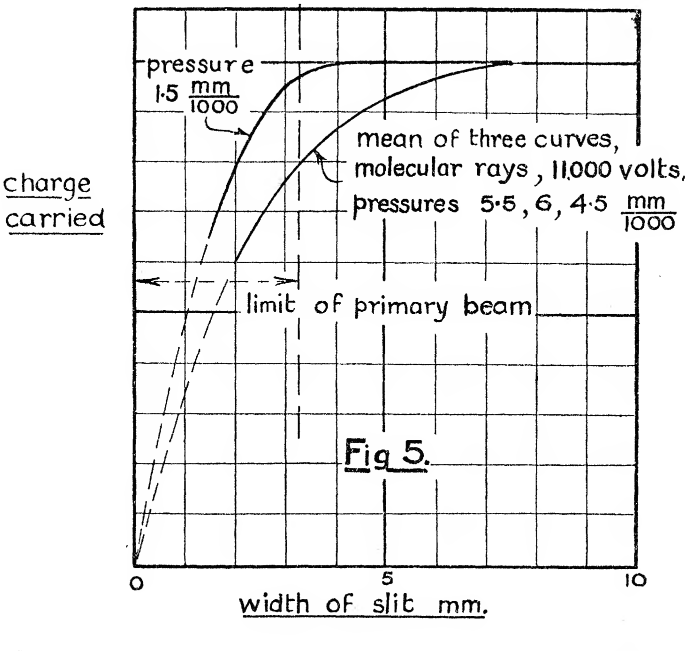


Fig 5.

thin layer, and was symmetrical in two dimensions instead of being in one as measured.

For these reasons, the most satisfactory way of comparing theory with the experiments is to deduce what shape of curve would theoretically be expected, and compare it with those obtained experimentally. Consider first the case of a hydrogen nucleus moving through hydrogen gas. The rays we are dealing with have an energy of roughly 10,000 volts, and the smallest scattering we can detect is about 1/300 radian, the largest about 3/100. The possible scattering particles in the hydrogen molecule are the two nuclei and the two electrons. To a fair approximation the nuclei can be regarded as acting independently, the connection between them being ignored. This can be seen as follows: the sideways velocity given to the nucleus by the particle, if the former is free to move, is equal and opposite to that which the particle itself receives, since they are of equal mass. The time of a collision is d/v, where v is the velocity of the ray and d is the distance over which the forces of the collision are important, which we may take as of the order of the diameter of the molecule. The velocity given to the nucleus is θv, where θ is the angle of scattering in radians. Hence the distance which the nucleus would move, if unconstrained by the rest of the molecule, is approximately $\frac{1}{2}\theta v \, . \, d/v = \frac{1}{2}\theta d$. Since θ is small, it follows that the displacement of the nucleus which would occur if it were unrestrained is a small fraction of the molecular diameter. Originally the nucleus was in equilibrium, and the force due to this small displacement from equilibrium will not be comparable with that between the ray and the nucleus (which approach within a distance less than $d/2$), unless the law of force between the constituent parts of the molecule is one which varies very rapidly with distance. It seems reasonable, therefore, to treat the nucleus as free to move.

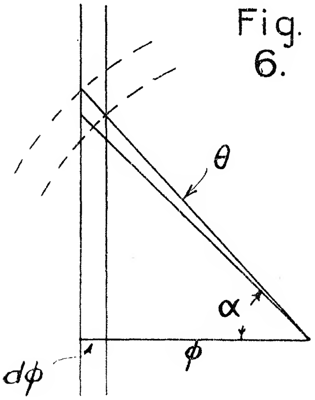


Fig. 6.

If a particle of mass m moving with velocity v shoots past an equal particle, which it repels with a force ϵ^2/r^2, the angle through which the direction of motion of the moving particle is deviated, supposed small, can be shown to be $2\epsilon^2/mv^2p$, where p is the perpendicular distance from the second particle on the original line of motion of the first. In our case this may be written $\epsilon/\mathrm{V}p$, where V is the potential difference through which the charge ϵ has fallen.

Now, in the experiments, the scattering is measured through a slit, while θ

is the radial scattering. Consider a screen at unit distance from the scattering particle (fig. 6). The chance of a ray being scattered between θ and $\theta + d\theta$ is the chance of its coming between p and $p + dp$ of a nucleus, and is $2\pi p \mathrm{N}\, dp$ per unit length, where N is the number of nuclei per unit volume. But $2\pi p \mathrm{N} dp = 2\pi \frac{\mathrm{N}\epsilon^2}{\mathrm{V}^2}\frac{d\theta}{\theta^3}$, since $p = \frac{\epsilon}{\mathrm{V}\theta}$; thus the surface density on the screen of particles scattered through an angle of θ is $\frac{\mathrm{N}\epsilon^2}{\mathrm{V}^2\theta^4}$. Hence the chance of a ray being scattered into the strip between ϕ and $\phi + d\phi$ is $2d\phi \int_0^{\pi/2} \frac{\mathrm{N}\epsilon^2}{\mathrm{V}^2\phi^4 \sec^4\alpha} \cdot \phi \sec^2\alpha\, dd = \frac{\pi}{2}\frac{\mathrm{N}\epsilon^2}{\mathrm{V}^2\phi^3}\, d\phi$, where $\phi = \theta \cos \alpha$.

In the actual experiment the scattering occurs at all points along the path of the rays, and the linear displacement of a ray at the slit will depend both on the angular deviation caused by the collision and on the distance from the slit at which the collision occurs. Without some limitation on the law we have been considering, it would be necessary to consider a large number of very small collisions. But these small collisions correspond to cases in which the ray is always at a considerable distance from the nucleus. If the ray is sufficiently distant, the forces will be small enough for the molecule to act almost as a rigid body, and, as it is neutral, the resultant force will be small. For these reasons it is desirable to limit the "collisions" which we consider to those in which p is less than a certain arbitrary quantity, which we will take as the radius of the hydrogen molecule, or about $1{\cdot}2 \times 10^{-8}$. We shall see later that the precise value taken does not affect the main conclusions. Let us call this value r, and the chance of a collision in a length dx, λdx, thus, $\lambda = \mathrm{N}\pi r^2$. The fraction of the total number of collisions which results in a scattering between ϕ and $\phi + d\phi$ is $\epsilon^2 . d\phi / 2r^2 v^2 \phi^3$ as long as $\phi > \epsilon / v_r$. (If ϕ is less than this value, θ, which is $\phi \sec \alpha$, may be less than ϵ / v_r, and the expression will be complicated, but since scattering as small as this could barely be detected, its effect will be ignored.) Then if l is the length of the scattering chamber (15 cm.), the fraction which gets through without any collision is $e^{-\lambda l}$. The fraction which make one collision only is $\lambda l e^{-\lambda l}$. Now, at the pressures actually used, comparatively few will make more than one effective collision. (It should be noticed that three-fourths of the collisions for which $p < r$ will give a value of $\phi < \epsilon / v_r$ after resolving perpendicular to the slit.) We can approximate to the effect of the few multiple collisions by regarding them simply as so many extra single collisions. Now the total number of collisions is $\lambda l x$ (the number of rays), so we shall suppose that λdx collisions occur in the interval dx, each of which is to be treated as a single collision.

The fraction $\frac{\epsilon^2 d\phi}{2r^2V^2\phi^3}$ of these make an angle between ϕ and $\phi+d\phi$ after collision. If y is the linear deviation at the slit and x is measured from the beginning of the scattering chamber $y=(l-x)\phi$. Hence a fraction of the rays equal to $\frac{\lambda\epsilon^2\, d\phi\, dx}{2r^2V^2\phi^3}$ lie within a width y and $y+dy$ where $dy=\phi dx$ and ϕ has all possible values. Thus the total fraction between y and $y+dy$ is $dy\int_{y/l}^{+}\frac{\lambda\epsilon^2 d\phi}{2r^2V^2\phi^4}=\frac{\lambda\epsilon^2 l^3}{6r^2V^2y^3}\,dy$, the upper limit of integration being an angle so large that the amount scattered through it can be neglected. Here $y/l>\epsilon/Vr$. Substituting for λ we get $\frac{\pi\epsilon^2 Nl^3}{6V^2y^3}$.

To allow for the finite width of the beam, we will suppose it of width $2a$, the intensity being uniformly distributed. If $2a$ is taken as the actual width over all, this will certainly give an over-estimate of the spreading to be expected, as in practice the intensity is much greater at the centre.

Let the strength of the beam be I, then the amount in a range of width $d\eta$ is $\mathrm{I}d\eta/2a$. The intensity at a point distant y from the axis is

$$\int_{-a}^{a}\frac{\pi\epsilon^2 Nl^3}{6V^2(y-\eta)^3}\cdot\frac{\mathrm{I}}{2a}\,d\eta \text{ if } y>a+\frac{l\epsilon}{Vr}$$

and

$$\int_{-a}^{y-l\epsilon/Vr}\frac{\pi\epsilon^2 Nl^3}{6V^2(y-\eta)^3}\cdot\frac{\mathrm{I}}{2a}\cdot d\eta+\frac{\mathrm{I}}{12a}\left(a-y+\frac{l\epsilon}{Vr}\right)\frac{\pi VNr^3}{\epsilon} \text{ if } a<y<a+\frac{l\epsilon}{Vr}.$$ [*]

By simple integration the amount outside a can be shown to be $\frac{\mathrm{I}\pi N\epsilon^2 l^3}{12V^2a}\left\{\frac{3}{2}\frac{Vr}{l\epsilon}-\frac{1}{4a}\right\}$ provided $2a>\frac{l\epsilon}{Vr}$ as was the case in these experiments. The amount outside $a+\xi$ where $\xi>\frac{l\epsilon}{Vr}$ is $\frac{\mathrm{I}\pi N\epsilon^2 l^3}{12V^2\xi(2a+\xi)\xi}$ and so depends only indirectly on r.

Taking the value of N corresponding to a pressure of 5/1000 mm., and treating the two nuclei in the molecule as independent, these expressions become $\mathrm{I}\times 1{\cdot}5\times 10^{-2}$ if $a=0{\cdot}17$ cm. and $\mathrm{I}\times 3{\cdot}3\times 10^{-3}$ if $a+\xi=0{\cdot}20$ cm. The value of $l\epsilon/V_r=0{\cdot}016$.

The corresponding values read off the curve of fig. 5 are $\mathrm{I}\times 1{\cdot}9\times 10^{-1}$ and $\mathrm{I}\times 1{\cdot}3\times 10^{-1}$. Thus the observed scattering exceeds that calculated on the assumption of the inverse square law by a factor of 13 in one case and 40 in the other.

The experiments in fig. 5, however, were made with molecular rays. As before, we may regard the nuclei in the positively charged molecule as acting independently. The effect of this is nearly to double N, but, on the other hand, after the collision the difference in velocities of the nuclei may result in the molecule being broken and the chance that the electron will go with either nucleus is probaby about even. Thus half the scattered particles will be neutral, and so will not be detected in the Faraday cylinder. The scattering of the remainder will be reduced by the force of the bond to an extent which it is difficult to determine; but if this change is small, the other two effects will roughly balance, and we should expect equal scattering for atomic and molecular rays, as indeed the experiments indicate. If the molecular ray is not broken, a given collision will only give it half the deflection which an atomic ray would have received. Thus we shall have twice the number of deflections, each of half the amount. With the law of force we are considering, it can be shown that this means that half as many are scattered per unit length through any specified angle. On this supposition, then, we should expect the scattering of molecular rays to be half that of atomic.

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[*] Unless $2a<l\epsilon/Vr$ when the limits are $l\epsilon/Vr-a<y<a+l\epsilon/Vr$ and the intensity is $\mathrm{I}V\pi Nr^3/6\epsilon$ for $a<y<l\epsilon/Vr-a$, but this case does not occur in practice.

The investigation above has taken no account of the electrons as scattering agents. Owing to their small mass, their direct effect is negligible and they can only act if they are so tightly bound to the nuclei that they form a practically rigid body with them for forces of the order we are considering. This seems improbable, and even if it were the case it would only increase the atomic scattering by a factor of 2, which is quite insufficient to account for the discrepancy. The velocities of the electrons on the Bohr theory is only of the same order as that of the rays, so the chances of collision are not greatly increased on this account.

It is known that, as a result of collisions, the positively charged hydrogen atom and molecule can pick up an electron and be neutralised, while the atom can even acquire a negative charge. Such neutralised rays would, of course, not be detected in the Faraday cylinder. This will reduce the total effect measured by the electrometer, but it does not seem probable that it will much affect the value found for the scattering. A ray which has been scattered will have the same chance of being neutralised as one which has not, and, since the scattering must be almost entirely the result of action between the nuclei, a ray that has been neutralised will have the same chance of being scattered as one that has kept its charge. Thus the scattered and unscattered rays will be reduced by neutralisation in the same proportion. It will, of course, be understood that in the above experiment we are only concerned with neutralisation in the scattering chamber. Rays which were neutral when passing the electric and magnetic fields would not be deflected and would not pass into the scattering chamber at all.

In order to account for the discrepancy it is necessary to suppose that there exists a field of force in the hydrogen molecule which, at distances of the order of 10^{-8} cm. from a nucleus, is many times stronger than the ordinary electrostatic force, and is capable of acting on a positively charged particle. This is not in conflict with Rutherford's results on the scattering of α-rays, as, owing to the much greater energy of the α-rays, a field of force amply sufficient to account for the above experiments would have no appreciable effect in their case. In addition, he is concerned with the interaction of two particles, one of which, the α-ray, contains exactly twice as many protons as electrons, and the other, the nucleus of the scattering atom, approximately twice as many. It is possible that this special relation may produce an almost complete compensation.

The field of force required may be due to an actual change in the law of force between nuclei at distances of this order; or if this law is taken as always being the inverse square, it must be the result of the mechanism, whatever it is, which keeps the molecule in stable equilibrium.

Note on "Stossstrahlen."

Glimme and Koenigsberger,* as a result of measurements with Faraday cylinders and thermopiles, believe that they have proved that in a beam of hydrogen positive rays, at pressures of the same order as those used in the above researches, the number of rays as measured by the Faraday cylinder is much greater (3–20 times) than that as measured by the thermopile. They interpret this as meaning that the large majority of the rays detected by the Faraday cylinder consist of slowly moving rays, which they call "stossstrahlen," and believe to be produced by impact from secondary rays, which themselves are produced by impact of the original beam. They give the energy of these slow rays as less than 200 volts. If such were the case, the interpretation given above of my experimental results would, of course, have to be considerably modified. Their view seems hard to reconcile with the fact that a beam of rays, even at comparatively high pressures, shows as a definite pencil, with fairly sharp edges. To test it further, I made an experiment in which a beam of rays was passed between a pair of parallel plates before falling on a Faraday cylinder. The plates could either both be earthed, or one could be earthed and the other raised to a known potential, large enough for all rays with energy as little as 200 volts to be swept on to the plates, and so prevented from reaching the Faraday cylinder. At a low pressure (3/1000 mm.) this caused no appreciable difference in the charge received by the cylinder. At a higher pressure the charge could either be increased or decreased, depending on whether the sign of the high potential plate was such as to drive positive or negative ions into the Faraday cylinder. But even so, the diminution in the charge observed was in no case comparable with that which would have occurred if there had been anything like the proportion of slow rays which Glimme and Koenigsberger require to explain their experiments. From theoretical considerations such an effect seems very improbable. Thus even if a ray is deviated through an angle of 1 in 30 (and both theory and experiment show that very few receive a greater deflection) the scattering particle, if of equal mass, would only acquire 1/30 of the velocity and 1/900 of the energy of the original ray, and would move off almost at right angles to the beam of rays. With an energy of 10,000 volts this gives 11 volts for the secondary ray, and it is hard to believe that this could then give rise to numerous tertiary rays in the direction of the original beam fast enough to make their way into the Faraday cylinder. It seems possible that Glimme and Koenigsberger did not take sufficient precautions (by magnetic field or otherwise) to prevent the escape of δ-rays from the Faraday cylinder, and so got a spurious effect.

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* 'Zeit. für Phys.,' p. 276 (1921).

Summary.

1. At a pressure of less than 1/100 mm. hydrogen positive rays of 10,000 volts mean energy suffer considerable small angle scattering in a distance of 15 cm.
2. This scattering is very much (10–20 times) greater than would be expected on theoretical grounds.
3. There must, therefore, be a field of force in the hydrogen molecule at distances of the order 10^{-8} from a nucleus, which is much stronger than would be expected from the inverse square law.
4. A subsidiary experiment throws great doubt on Glimme and Koenigsberger's "stossstrahlen."

In conclusion, I wish to express my very sincere thanks to Mr. W. S. Farren, M.A., Trinity College, for designing and making the slit mechanism shown in fig. 2 and for his help in preparing the illustrations. I must also record my deep gratitude to my father, Sir J. J. Thomson, O.M., for his valuable advice on many occasions during the progress of these researches.